

United States Continuation-in-Part Patent Application for:

METHOD OF ETCHING SILICON NITRIDE

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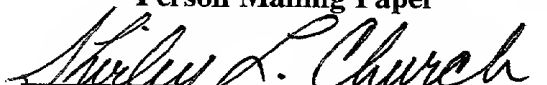
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1 [0001] **METHOD OF ETCHING SILICON NITRIDE**

2 [0002] Statement of Related Application

3 [0003] This application is a continuation-in-part of United States Patent Application
4 Serial No. 09/291,682, filed April 13, 1999, which is currently pending. This application
5 is related to co-pending United States Patent Application Serial No. 08/907,448, which was
6 filed on August 8, 1997.

7 [0004] **BACKGROUND OF THE INVENTION**

8 [0005] Field of the Invention

9 [0006] The present invention relates generally to a fabrication process for manufacturing
10 semiconductor devices. More particularly, the present invention relates to a method and
11 etchant for etching silicon nitride (SiN_x) when the photoresist used to pattern the silicon
12 nitride is a deep UV photoresist.

13 [0007] Background

14 [0008] Subtractive dry etching is conventionally used to pattern silicon nitride for use in
15 semiconductor devices. Conventional dry etching (plasma etching) processes include
16 physical bombardment by inert ions, chemically reactive ion etching, and combinations
17 thereof. Dry etching generally involves exposing the SiN_x to a gaseous plasma created by
18 RF excitation of a plasma source gas in a vacuum system. The RF excitation generates ions,
19 free radicals and other excited species from the source gas. The SiN_x surface is contacted
20 by the excited species, which typically are designed to chemically react with as well as
21 physically bombard the SiN_x surface. Plasma etching relies on diffusion to transport the
22 excited species to the surface being etched, and is generally isotropic. In order to provide
23 anisotropic etching, it is necessary to develop a voltage between the plasma and the substrate

1 surface to be etched, to accelerate excited species (particularly ions) toward the substrate
2 surface. Because of this acceleration, it is possible to achieve anisotropic etching, whereby
3 the etching proceeds at an appreciable rate in a direction normal to the surface of a wafer,
4 but does not proceed at an appreciable rate in lateral directions. However, unless process
5 parameters are carefully controlled, etching in the lateral direction, also referred to as
6 sidewall attack, may occur. Depending upon the particular device or feature being
7 fabricated, some deviation from a perfect anisotropic etch may be tolerable, although it is
8 usually desirable to minimize such deviations. For example, an etched feature that has a
9 sidewall included angle (between the sidewall surface and the horizontal surface of the
10 substrate beneath the sidewall) as low as 80° instead of the ideal 90° (where the sidewall
11 is perpendicular to the surface beneath the sidewall), may be acceptable in some instances,
12 but is not desirable. Such an undercut from top toward bottom of the sidewall can cause
13 problems during subsequent processing steps. For a more detailed description of dry
14 etching processes, see Runyan and Bean, Semiconductor Integrated Circuit Processing
15 Technology, Ch. 6.3, pp. 269 - 280 (1990), which is incorporated herein by reference.

16 [0009] A layer of SiN_x may be patterned during a dry etching process by protecting
17 portions of the layer surface from the etchant, while exposing other portions, using a mask.
18 These masks are frequently made of photoresist which is typically a polymeric material, and
19 most typically an organic-based material. "Hard masks", typically comprising a metal or
20 a silicon-comprising compound, or other inorganic materials, may also be used to selectively
21 expose SiN_x to plasma. However, it is generally more difficult and more expensive to
22 pattern very small features into a hard mask than to pattern such features into a photoresist.
23 As a result, photoresist masks are preferable for many applications.

24 [0010] However, the plasma etchant etches the organic-based photoresist masking
25 material simultaneously with the substrate exposed through the mask. Photoresist erosion
26 (etching away) may undesirably lead to punch through. For example, during the etching of

1 SiN_x, there may be exposure of mask protected SiN_x surfaces prior to complete etching
2 through of SiN_x surfaces which are intentionally exposed through the mask. This problem
3 is exacerbated with anisotropic etching processes, which generally etch away photoresist at
4 a faster rate than isotropic etching processes. In addition, an anisotropic etching process
5 generally reduces the selectivity for SiN_x relative to photoresist, where the selectivity is the
6 ratio of the etch rate of the SiN_x to the etch rate of the photoresist. While the possibility of
7 punch through of the photoresist may be reduced by increasing photoresist thickness, it is
8 preferable to use a photoresist mask that is as thin as possible for the reasons previously
9 given. The minimum photoresist thickness that may be used without punch through depends
10 upon the thickness of SiN_x being etched, and the selectivity of the etching process.

11 [0011] When an I-line photoresist is used as a patterned mask for the etching of the SiN_x
12 layer, the photoresist layer can be relatively thick (as thick as 12,000 to 13,000 Å).
13 However, the minimum feature size for an I-line photoresist is in the range of about
14 2500 Å. To obtain smaller feature sizes, in the range of about 1500 Å, it is presently
15 necessary to use a Deep UV (DUV) photoresist as the patterned masking material for the
16 etching of the SiN_x. This requires a reduction in the thickness of the photoresist layer, since
17 DUV photoresist thickness is typically limited to less than about 7000 Å for optical reasons.
18 The reduced thickness in the DUV photoresist layer makes etch selectivity of the SiN_x in
19 preference to the photoresist more critical. When an I-line photoresist is used, a reduction
20 in feature size from about 10,000 Å to about 2500 Å results in a decrease in the selectivity
21 for SiN_x in preference to the I-line photoresist. For example, the typical selectivity of
22 SiN_x : I-line for a feature size of about 10,000 Å ranges from about 2 : 1 to about 3 : 1 ;
23 while the selectivity for a feature size of about 2500 Å ranges from about 1 : 1 to about
24 2 : 1. In addition, when the feature size is reduced from about 2500 Å to about 1500 Å, the
25 etch rate for the SiN_x typically decreases because of diffusion limitations pertaining to the
26 removal of etch reaction by-products from the smaller openings to the smaller features.

1 [0012] An illustrative example of the use of an I-line photoresist in the patterned etching
2 of SiN_x is provided in the PCT published application WO 96/16437, published May 30,
3 1996, and titled: Silicon Nitride Etch Process With Critical Dimension Gain. The etched
4 SiN_x feature size is about 5,000 Å, and the plasma source gas used to etch the silicon nitride
5 is a mixture of CHF_3 and O_2 , where the ratio of CHF_3 : O_2 is at least 6 : 1.

6 [0013] To be able to use a DUV photoresist, it is necessary to be able to maintain an
7 adequate selectivity to prevent punch through of the thin photoresist and to be able to obtain
8 an acceptable etch rate for the SiN_x .

9 [0014] **SUMMARY OF THE INVENTION**

10 [0015] We have discovered a method of providing improved selectivity for an underlying
11 layer during plasma etching of that underlying layer through an organic-based photoresist.
12 In particular, when the plasma source gas includes a fluorine containing compound, sulfur
13 dioxide (SO_2) is added to the plasma source gas. The method is particularly advantageous
14 when the organic-based photoresist is a DUV photoresist and when the etched feature size
15 is less than about 2500 Å. The method is especially useful for anisotropic plasma etch
16 processes, but is useful for isotropic etching processes as well.

17 [0016] A particularly preferred embodiment is the anisotropic etching of silicon nitride
18 (SiN_x) through a patterned, DUV, organic-based photoresist mask. The plasma source gas
19 includes a fluorine-comprising compound and SO_2 . Preferably, the plasma source gas
20 includes argon (Ar) or another inert gas which provides a good source for ions useful in the
21 anisotropic etching process. Preferred fluorine-comprising compounds are inorganic and
22 include nitrogen trifluoride (NF_3) and sulfur hexafluoride (SF_6), by way of example and not
23 by way of limitation. In addition, hydrogen bromide (HBr) may be added to the plasma
24 source gas to assist in profile control during etching of the silicon nitride feature.

1 [0017] **BRIEF DESCRIPTION OF THE DRAWINGS**

2 [0018] Figure 1 shows a trench etched in SiN_x.

3 [0019] Figure 2 shows a preferred apparatus for practicing the present invention.

4 [0020] Figure 3 shows a cross-section of a preferred apparatus for practicing the present
5 invention.

6 [0021] Figure 4 shows a preferred apparatus for practicing the present invention that
7 incorporates a computer for purposes of process control.

8 [0022] **DETAILED DESCRIPTION OF THE INVENTION**

9 [0023] Conventional anisotropic etching processes typically include a chemically
10 reactive etchant species, frequently generated from at least one halogen species, and
11 preferably generated from a fluorine-containing compound. Inert gases such as helium,
12 argon, krypton, and xenon may also be used to provide ion bombardment in an anisotropic
13 etching process. Inert gases are preferred for ion production in an anisotropic process,
14 because ions generated from inert gases are effective at bombarding the surface being
15 etched, and are unlikely to chemically react with adjacent surfaces (which may cause lateral
16 etching). Further, the use of an inert gas as a diluent allows for better control and uniformity
17 of the plasma. Argon (Ar) is very effective at providing ion bombardment during the
18 etching of a substrate. However, a combination of a chemically reactive etchant species with
19 active ion bombardment of the substrate surface generally results in a low selectivity for
20 SiN_x relative to photoresist. The selectivity range is generally from about 1 to about 1.5.
21 As a result, these conventional anisotropic etching processes require the use of a thick layer
22 of photoresist.

1 [0024] The inventors have discovered that adding sulfur dioxide (SO_2) to a plasma source
2 gas including one or more fluorine-containing gases during the patterned, anisotropic
3 etching of an underlying layer protects the photoresist during etching of the underlying
4 layer. As a result, the selectivity for the underlying layer is improved relative to the
5 photoresist. For example, during etching of a SiN_x layer through a DUV photoresist,
6 addition of SO_2 to the plasma source gas increases the selectivity for SiN_x relative to
7 photoresist. By adding SO_2 to a fluorine-comprising source gas, the inventors were able to
8 improve selectivity for SiN_x in preference to a DUV photoresist from about 1.5 : 1 (SiN_x :
9 DUV) to about 2.1 : 1. Further, the inventors estimate that this selectivity may be increased
10 to as high as 3 : 1 by process optimization. As a result, thinner layers of photoresist may be
11 used, resolution may be increased, and the possibility of shading damage to underlying
12 substrate features is reduced.

13 [0025] Typically, the addition of an oxygen-containing gas to the plasma source gas
14 increases the etch rate of photoresist (which is an organic material and reacts rapidly with
15 active oxygen species). This decreases the selectivity of the process for SiN_x relative to
16 photoresist. For example, U.S. Patent No. Re. 30,505 to Adir Jacob, reissued February 3,
17 1981, describes a process to facilitate the etching of silicon nitride (among other materials)
18 using a "cold" plasma (under 325 °C), where the plasma source gas comprises a binary
19 mixture of a halocarbon and oxygen. The preferred halocarbon comprises only one carbon
20 atom, such as tetrafluoromethane. Typically oxygen makes up between about 8.5 % and 25
21 % of the volume of the plasma source gas mixture. It is disclosed that "(a further) increase
22 in the mole fraction of oxygen (up to 0.5) tends to result in an excessive etch rate of the
23 dielectric layer (SiO_2 layer underlying the SiN_x) with associated degradation of the
24 photoresist mask and line-line resolution".

1 [0026] The improvement in selectivity observed upon addition of SO₂ to the plasma
2 source gas was unexpected by applicants. While not intending to be limited as to any
3 explanation as to why the present invention works, it is believed that the SO₂ interacts with
4 the photoresist and fluorine reactive species from the plasma to create a passivation layer
5 on the surface of the photoresist which slows the etch rate of the photoresist. Other oxygen-
6 containing gases which do not contain sulfur do not appear to have a similar effect.

7 [0027] While anisotropic etching processes are the most likely application for the present
8 invention, and the most preferred embodiment of the invention provides for the use of a
9 plasma source gas which includes argon, the inventors believe that the invention may be
10 applied to a plasma etch process that does not involve ion bombardment. For example, in
11 an isotropic process for etching SiN_x, the addition of SO₂ to a plasma source gas that
12 includes a fluorine-comprising compound is expected to improve the selectivity of the
13 etchant for SiN_x relative to a photoresist. Diluent gases such as He, N₂, Ar, Kr and Xe may
14 also be added to the plasma source gas, to provide for better plasma control and uniformity
15 in an isotropic etch process, as well.

16 [0028] One skilled in the art will recognize that a photoresist itself will generate reactive
17 species during a plasma etching process. Since these reactive species affect the overall
18 chemistry of the etch process, the relative amounts of the constituents of the plasma source
19 gas may need to be adjusted depending on the particular photoresist in use. In any case, one
20 skilled in the art can, with minimal experimentation, optimize a particular source gas for the
21 task at hand.

22 [0029] We have discovered that by adding SO₂ to the plasma source gas, due to the
23 improvement in selectivity for SiN_x relative to photoresist, it is possible to significantly
24 reduce the thickness requirement for the photoresist masking layer. For example, a number
25 of semiconductor device fabrication processes require the anisotropic etching of SiN_x
26 features to a depth of about 1500Å - 6000Å in a layer of SiN_x, with resolutions of

1 0.25 microns and lower in a lateral direction. Such features have an aspect ratio of about
2 0.6 - 2.4, *i.e.*, the ratio of the etch depth to the smallest lateral dimension of the feature. A
3 trench etched in SiN_x having a depth of 2000 Å and a width of 2500 Å is an example of such
4 a feature. To achieve a depth of 2000 Å using a conventional DUV photoresist without
5 punch through, it is generally necessary to use a resist thickness of about 5000 - 7000 Å.
6 However, by adding SO₂ to the plasma source gas, it is possible to achieve a depth of
7 2000 Å using a photoresist thickness as low as about 3000 - 4000 Å.

8 [0030] Typically, the etch rate of the SiN_x is selected to be about 1000 to 2000 Å/min.,
9 the rate which is achievable with conventional etchants. Slower etch rates would lead to
10 higher processing costs, and faster etch rates may not be controllable using current
11 processing apparatus. This is not to limit the invention to a maximum etch rate of 2000 Å,
12 however. The inventors have observed that the addition of SO₂ to the plasma source gas
13 does not appear to have a significant effect on the etch rate of SiN_x in a direction normal to
14 the substrate. However, the addition of SO₂ does lead to an improvement in the anisotropy
15 achievable in an anisotropic etch process. Without SO₂, etched regions are usually narrower
16 at the bottom than the top of a trench, *ie.*, the sidewalls are undercut from the top toward the
17 bottom of an etched trench. The walls may form angles as low as 80 - 85° with the
18 horizontal substrate surface. However, with the addition of SO₂, the amount of taper is
19 reduced, and the sidewalls are more perpendicular with the substrate, with angles of about
20 87 - 90°.

21 [0031] The present invention may be used in to fabricate any anisotropically etched
22 feature in SiN_x. For example, the present invention may be used to fabricate trenches, vias,
23 and/or lines in SiN_x. Figure 1 shows a trench 100 fabricated in a substrate having a layer
24 110 of SiN_x. The trench has a depth 102, a top width 104, and a bottom width 106. The
25 trench has side walls 120 and a bottom surface 130. Bottom surface 130 is in the plane of
26 the substrate. A photoresist layer 140, having an initial thickness 141, was used to pattern

1 trench 100. A portion 142 of photoresist layer 140, having an initial overall thickness 143,
2 was etched away during etching of trench 100 in SiN_x substrate 110 to a depth 102. A
3 portion 144 of photoresist layer 140, having a thickness 145, remains after etching. Dashed
4 lines are used to show photoresist portion 142 which was removed during the etching
5 process. Portion 144 is generally removed using a separate process after the etching of
6 trench 100.

7 [0032] **Preferred Apparatus**

8 [0033] The present invention may be practiced in any apparatus adapted to expose a
9 substrate to a plasma. Preferably the apparatus is capable of applying a bias voltage to the
10 substrate. Preferably, the apparatus includes devices for the independent control of a plasma
11 source power used to generate the plasma, from a bias power used to generate substrate bias
12 voltage. This enables the selection of a desired plasma density independently of the
13 selection of the amount of energy with which ion bombardment occurs upon the substrate
14 surface. The CENTURA® DPS™ silicon etch system available from Applied Materials,
15 Inc., of Santa Clara, California, is an example of a system which provides for such
16 independent control.

17 [0034] However, the present invention may be practiced in an apparatus having a plasma
18 source power and bias power which are not separately controllable, or in any other type of
19 apparatus adapted to expose a substrate to a plasma.

20 [0035] Figure 2 (prior art) shows a preferred etch chamber 200 of the type used in the
21 CENTURA® DPS™ silicon etch system. Etch chamber 200 includes a ceramic dome 202,
22 and a standard monopolar electrostatic chuck (ESC) 204. Gas is introduced into the
23 chamber via four ceramic gas injection nozzles 208 for uniform gas distribution. Chamber
24 pressure is controlled by a closed-loop pressure control system 210 with a throttle valve 212.

1 [0036] Etch chamber 200 includes an inductive plasma source generator, typically
2 operating at a frequency tuned at approximately 12.56 MHz, which generates and sustains
3 a high density plasma (*i.e.*, typically having an electron density of at least about 10^{11} e/cm³).
4 A 13.56 MHz RF power source is frequently applied to the substrate support pedestal
5 (cathode) to create a bias voltage on the substrate surface. In the preferred apparatus, each
6 watt of bias power generally produces about - 1 Volt of substrate bias. The conversion from
7 bias power watts to substrate bias voltage is highly dependent upon chamber geometry, and
8 may be different in a different apparatus. The independently controlled plasma source
9 power permits independent control of ion energy and ion density, which provides highly
10 uniform plasma (< 5% variation) with a wide process window over changes in source and
11 bias power, pressure, and plasma source gas chemistry.

12 [0037] Figure 3 (prior art) shows a nonscaled schematic of a vertical cross-section of an
13 etch chamber 300, of the kind referenced in Figure 2. Electrostatic chuck 302 is adapted to
14 hold a substrate 304. Electrostatic chuck 302 overlies electrode (substrate pedestal) 306,
15 which is electrically connected to an independently controlled power source 308. The upper
16 portion 313 of the chamber wall is typically comprised of a ceramic material. The lower
17 portion 310 of the chamber wall is typically comprised of an anodized aluminum surface
18 322 overlying an aluminum body 310 which is electrically grounded through switch 315.
19 A plasma source gas is introduced into and distributed throughout chamber 300 by means
20 of a gas distributor 312 peripherally disposed above substrate 304. Plasma ions are formed
21 from the plasma source gas by applying an RF current to an inductive coil plasma generator
22 314, which is connected to an independently controlled plasma generator (RF) power source
23 316. The cathode electrode 306 is electrically biased with respect to the anode electrode
24 (lower portion 310 of the chamber wall) by applying an RF voltage to the cathode electrode
25 306 via power source 308, so that the plasma ions formed in chamber 300 are attracted
26 toward and energetically impinge upon substrate 304. Spent process gas and etchant by-

1 products are exhausted from chamber 300 through an exhaust system 318. A throttle valve
2 320 is provided in exhaust system 318 to control the pressure in the chamber 300. A more
3 detailed description of etch chamber 300 is found in U.S. Patent No. 5,779,926, issued
4 July 14, 1998, to Ma et al., which is incorporated herein by reference.

5 [0038] **Preferred Process Parameters**

6 [0039] In the preferred apparatus, the plasma source power is preferably between about
7 200 and 2000 Watts during processing, which should be adequate to ionize a sufficient
8 percentage of the gas molecules to generate a high density plasma. Lower plasma source
9 powers may not generate a high density plasma, and an apparatus capable of providing
10 higher plasma source powers are more expensive. The bias power is preferably between
11 about 50 and 500 Watts, which generates an DC voltage difference between the plasma and
12 the substrate of about 50 to 500 Volts. Lower bias voltages may result in an etch rate that
13 is too slow, and higher bias voltages may cause damage to the substrate, and may lead to
14 faster photoresist erosion. The bias frequency is preferably about 13.56 MHz, which
15 generally gives good profile control, but may vary over a wide range from as low as 30 kHz
16 up to multiples of 13.56 MHz.

17 [0040] Preferably, the total pressure in the chamber is maintained between about 4 and
18 70 milliTorr (mTorr) during etching. Lower pressures may lead to rounding of corners in
19 the etched features, and higher pressures may lead to decreased etch rates.

20 [0041] In the preferred apparatus, the amount of fluorine-comprising gas fed into the
21 chamber is preferably between about 20 and 300 sccm, and more preferably between about
22 20 to 100 sccm. The amount of Ar gas fed into the chamber is preferably between about
23 20 and 200 sccm, and more preferably between about 50 to 150 sccm. The amount of SO₂
24 is preferably between about 5 and 50 sccm, and more preferably between about 10 and 30
25 sccm. Providing too much gas in aggregate may make it difficult to maintain a process

1 chamber vacuum in the desired range, which in turn will decrease the plasma density and
2 the etch rate. Greater amounts of fluorine-comprising gas may lead to a higher
3 concentration of reactive species, which may lead to an etch having some degree of isotropy.

4 Lesser amounts of fluorine-comprising gas may lead to a lower concentration of reactive
5 species and undesirably slow etch rates. Lesser amounts of Ar gas may lead to less ion
6 bombardment, which may lead to slower etch rates due to passivation layers forming on the
7 surfaces to be etched, and may result in polymeric residues on the etched feature surface.
8 The use of gas volumes outside of these preferred ranges may work, particularly in an
9 apparatus having significant volumetric and geometric differences from the preferred
10 apparatus, or with process parameters significantly different from the preferred process
11 parameters.

12 [0042] As used herein, the term “element-containing gas” or “element-comprising
13 compound” refers to a gas or compound which includes an atom of the particular element.
14 For example, carbon tetrafluoride (CF₄), nitrogen trifluoride (NF₃) and sulfur hexafluoride
15 (SF₆) are “fluorine-comprising compounds” which are fluorine-containing gases under the
16 process conditions used during plasma etching. The terms “including” and “comprising”
17 are used, *inter alia*, to describe a plasma source gas which is a mixture of the particular
18 gases included, and which may include additional gases as well. The terms “including” and
19 “comprising” are not intended to limit when the gases are mixed, such that a plasma source
20 gas including CF₄ and Ar may be implemented by feeding the two gases into a vacuum
21 chamber via separate routes.

22 [0043] In terms of percentages, the amount of fluorine-containing gas is preferably
23 between about 20% and 60% by volume of the plasma source gas, and more preferably
24 between about 25% and 35%. The amount of Ar is preferably between about 20% and 60%,
25 and more preferably between about 50% and 60%. The amount of SO₂ is preferably
26 between about 2% and 20%, and more preferably between about 5% and 15%.

1 [0044] The plasma source gas may optionally include hydrogen bromide (HBr). The
2 addition of HBr to the plasma source gas results in the formation of silicon oxybromide
3 (Si_2OBr_6) and/or bromosilane (SiH_3Br), which provides sidewall passivation and improved
4 etch profile control. The amount of HBr is preferably between about 10% and 60%, and
5 more preferably between about 20% and 40%, by volume of the plasma source gas.

6 [0045] In terms of the atomic and/or molecular ratios of plasma source gases which
7 provide the desired results, for the preferred embodiment fluorine-comprising gas, CF_4 , the
8 preferred range for the ratio of CF_4 : Ar is between about 0.1 : 1 to about 10 : 1, and the most
9 preferred range is between about 0.5 : 1 to about 1 : 1. The preferred range for the ratio of
10 CF_4 : SO_2 is between about 50 : 1 to about 1 : 1, and the most preferred range is between
11 about 8 : 1 and about 3 : 1. When the fluorine-comprising source gas is other than CF_4 , one
12 skilled in the art must take into account the amount of energy which is required to generate
13 fluorine-containing etchant species from the fluorine-comprising source gas.

14 [0046] Preferably, the substrate is cooled during etch processing, generally by means of
15 a coolant passed to a channel in the substrate support electrode (not shown). In addition, a
16 flow of a coolant such as helium may be passed between the substrate and the substrate
17 support platen to enhance cooling and maintain the temperature of the substrate within the
18 desired range, preferably from about 20°C to 100°C, and more preferably from about 40°C
19 to 60°C.

20 [0047] Note that the optimal value for any particular process parameter (including the
21 amount of feed gas components), is highly dependent upon a variety of factors, including
22 the geometry of the particular apparatus used, as well as the values of the other process
23 parameters. It is therefore possible to depart from the preferred ranges set forth herein
24 without departing from the scope of the invention. In any event, one of skill in the art
25 should be able to determine optimal process parameters (including amounts of feed gas
26 components) for use with a particular apparatus and/or subset of process parameters with

1 minimal experimentation.

2 [0048] **Computer Control**

3 [0049] Preferably, the apparatus used to practice the present invention is adapted to be
4 controlled by a computer. Figure 4 shows a computer 400. Computer 400 comprises a
5 processor 402, memory 404 adapted to store instructions 406, and one or more ports 408.
6 Processor 402 is adapted to communicate with memory 404 and to execute instructions 406.
7 Processor 402 and memory 404 are also adapted to communicate with one or more ports
8 408. Ports 408 are adapted to communicate with a plasma etch chamber 412. Plasma etch
9 chamber is adapted to carry out process steps in accordance with signals received from
10 processor 402 via ports 408. Preferably, computer 402 can control the composition and feed
11 rate of the plasma source gas, the temperature, the pressure in the chamber, the bias power,
12 the plasma source generation power. Preferably, computer 402 is adapted to receive
13 measurements that describe the condition in the chamber, and adapt the process variables
14 accordingly. Computer 400 is typically used in combination with a medium (not shown)
15 which contains data which enables control of the apparatus to practice the method of the
16 present invention.

17 [0050] **Examples**

18 [0051] Example 1 (Comparative Example)

19 [0052] With reference to Figure 1, a layer of DUV photoresist 140 (obtained from
20 Shipley Company) about 7,000 Å thick was patterned (on top of a layer of SiN_x 110), to
21 have an opening 104 about 5,630 Å wide. The SiN_x layer 110 was then anisotropically
22 etched with a conventional plasma source gas, using the preferred apparatus described
23 above. The conventional plasma source gas was a mixture of CF₄ and Ar, and the CF₄ was
24 fed into the chamber at a rate of about 80 sccm, while the Ar was fed into the chamber at a

1 rate of about 120 sccm. The pressure in the chamber was maintained at 4 mTorr. The
2 plasma source power was 1,000 W, and the bias power was 200 W. The substrate support
3 platen temperature was maintained at about 50°C. The etch time was 60 seconds.

4 [0053] After the etch process, a trench similar to that of Figure 1 was observed. The
5 depth 102 of the trench was about 4700 Å. The top width 104 of the trench was about
6 5600 Å, and the bottom width 106 of the trench was about 4700 Å. There was an
7 approximately linear taper from top to bottom. The angle θ formed between the planes of
8 sidewalls 120 and bottom surface 130 was about 86.2°. About 3100 Å resist was eroded
9 during the etch, *i.e.*, thickness 143 was about 3100 Å, for a selectivity of about 1.53
10 (4750 Å / 3100 Å) for SiN_x relative to photoresist.

11 [0054] Example 2

12 [0055] A substrate was processed in a manner identical to that of Figure 1, except that
13 the plasma source gas included CF₄, Ar, and SO₂, where the relative gas feed rates were
14 about 80 sccm, about 120 sccm, and about 20 sccm, respectively.

15 [0056] After the etch process, a trench similar to that of Figure 1 was observed. After
16 a similar etch time, the depth 102 of the trench was about 4750 Å, the same as that of
17 Example 1, indicating that the addition of SO₂ did not slow the etch rate of SiN_x. There was
18 an approximately linear taper from top to bottom. The angle θ between the sidewall and the
19 substrate was about 88°, closer to perpendicular than in Example 1, indicating that the
20 addition of SO₂ enables a more ideal anisotropic etch. About 2300 Å of resist was eroded
21 during the etch, *i.e.*, thickness 143 was about 2300 Å. The selectivity was therefore about
22 2.07 (4750 Å / 2300 Å), higher than that of Example 1, indicating that the addition of SO₂
23 slows the etch rate of photoresist.

1 [0057] While the foregoing is directed to preferred embodiments of the invention, other
2 and further embodiments of the invention may be devised without departing from the basic
3 scope thereof. The scope of the invention is determined by the claims that follow.